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Fermilab

A REPLY TO THE QUESTION FROM HEPAP:

"ARE THE DOUBLER MAGNETS GOOD ENOUGH FOR THE COLLIDER?"

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Shortly before the Woods Hole meetin in June, S. Treiman, chairman of the HEPAP, sent a letter to the director of Fermilab asking him to clarify several points regarding the Tevatron project. One of the questions was whether our best magnets are suitable as is for the $\bar{p}p$ collider. I was asked to produce a document that may be useful for the director in preparing his reply to this question.

Originally, I hoped to expand the document I prepared for this so that it would become more technical and therefore would be suitable as a UPC report. However, this endeavor has turned out to be more painful to me than I anticipated. Furthermore, I was told that the question of magnet quality was not a big issue at Woods Hole and the document I prepared was not really needed to defend the Tevatron project. This did not encurage my effort to produce a decent report out of the not-so-technical document. It is nevertheless undeniable that I did spend a few agonizing hours musing over the question and trying to be honest to a reasonable degree. In issuing the original document without any change or amplification, I am simply trying to establish the credit for my modest effort which otherwise would be forgotten completely. It is also hoped that the report would be useful for anyone in wiggling his way out whenever similar questions on the doubler magnet quality were asked by outsiders.

Question: Are the present best magnets (or magnet) suitable as is for the $p\bar{p}$ collider at luminosity = 10^{30} ?

Answer: Yes, to the best of our present knowledge regarding the beam lifetime in a ring, we have produced more than (X)* dipoles that should be suitable for the collider. The justification for making this statement comes from various references given in this report. The present report is a summary of these documents; it also explains conditions that must be met in order for this answer to be true. The explanation is necessary because of the naiveté of the question for a complex problem. It is of course assumed here that the question of the structural integrity when magnets experience many thermal cycles is a separate one. The statement above regarding more than (X)* dipoles is true if their structural integrity is as sound as that of magnets TB0329 and TB0343. It is worth remembering here that we have produced a string of six dipoles (TA0233 to TA0238) that are entirely acceptable. We believe this is a definite indication that the necessary quality control is within our technological capability.

Conditions To Be Met

Best magnets we have made so far are suitable for $p\bar{p}$ collider provided the following conditions and requirements are satisfied.

A. Conditions directly related to magnets.

1. Structural integrity (often refered to as the "vertical plane problem").

2. Present criteria on various properties that are listed in the

*Censored at the director's office.

magnet summary sheet be strictly maintained together with the specification for the correction system.[1] Watch for the average values of quadrupole (normal and skew) and normal octupole components since they are especially important for the storage capability of the ring.

3. If it becomes necessary to relax the criteria for the quadrupole components b_1 and a_1 in order to assure the structural integrity, be prepared to have harmonic correction systems of normal and skew quadrupoles.[2,3] The main concern here is the mismatching in the beam transfer process which leads to the beam emittance dilution and the control of momentum dispersion function (horizontal and vertical) at the crossing point.

4. More than $\sim$ 30 magnets should be available at one time for $\sim$ 30 consecutive locations so that some kind of optimum arrangement can be tried.[4]

5. The specifications for the alignment of dipoles[1] and quadrupoles[1,5] should be followed strictly.

6. Field quality of special quadrupoles (and maybe even dipoles) near the crossing point in which the beta function becomes very large when the low-beta insertion is tried should be separately specified so that they do not contribute significantly to the tune spread of the beam and to the widths of various resonances.

B. Conditions not directly related to magnets.
We now know that, for the beam storage, these are equally important as the magnet field quality.

1. Position detectors should have the resolution of better than 1 mm for both p and $\bar{p}$ beams. Control of the closed orbit should be good to less than 2 mm and should be better at the crossing point.

2. Reliable beam profile monitors. At 1 TeV/c, the system developed at CERN which utilizes the synchrotron radiation may be superior to others. The Main Ring Group is planning to build and install such a system.

3. Schottky scan system for the measurement of the tune spread, the momentum spread and ripples.

4. A good control of the chromaticity. This is probably one of the most important for the beam storage.[6] Because of the relatively small momentum spread of the beam, two independent sets (compared to the four advocated by others) should be adequate.

5. Control of the power supply ripples. This is another of the important items rediscovered recently. The present specification[7] for the special holding power supply to be used in the storage mode should be good enough for the collider with the anticipated tune ripple of less than 10^{-5}.

6. Better understandings of the RF noise problems.[6,8] This is by now established both in our main ring and in the CERN SPS as one of the main culprits for limiting the beam lifetime. With the 50 MHz RF system, the problem for us should be less serious than the one for the SPS with the 200 MHz system.

It should be emphasized that the important thing is not to have everything available on the day one but rather to have the flexibility to upgrade the existing system and to have space (yes, SPACE cannot be created so easily later) for new devices needed. The experience we have acquired in the past ten years tells us that this is a viable approach when a project must be finished in the minimum amount of time with a limited fund. So far, the design and the construction of the doubler have been such that nothing mentioned above as the necessary conditions and requirements is excluded.

Summary of What We Know Today Regarding Beam Storage

The beam storage in a ring is a complicated problem with a large number of factors influencing the beam behavior and the beam lifetime. It is not very meaningful to ask whether a particular magnet is or is not good enough to be used for a storage ring unless other equally important factors are specified together. This is true even for relatively simple fixed-target accelerators and a good example is our main ring. If isolated from the correction system and the feedback system, the field quality of the main ring magnets is definitely not good enough to be used for an accelerator which must deliver a 400 GeV beam of 2.7×10^{13} protons per pulse. The progress made during the past year or so in the understanding of beam lifetime in a storage ring is especially significant in properly identifying the most important factors such as the power supply ripples, the chromaticity and the RF noise. It is certainly an unjustified exaggeration to say that the significance of the magnet field quality has been downgraded. At the same time, it can be said that accelerator physicists have begun to look at the requirements for the magnet field quality in proper perspective. For example, it may be esthetically pleasing to have magnets whose effect on the beam lifetime is less than one percent of the effect arising from the beam-beam interaction but this can hardly be regarded as practical. From what we know now, we believe that, if conditions listed above are satisfied in the doubler, the effect of the magnets on the beam lifetime should be of the order of 10% compared to the effect coming from the beam-beam interaction with its linear tune shift of ~ 0.003. As can be seen from the list of references, our knowledge comes primarily from the recent beam studies in the CERN ISR and SPS[9-12] as well as in our main ring.[6] In spite of the new and promising approaches in the recent theoretical works (S. Kheifets,[13] A. Ruggiero, F. Mills and others) and the ambitious scope of the recent computer simulations (J. Tennyson, D. Neuffer, E. Keil, B. Chirikov and others), we believe it is still too early to depend on what these works predict. It is also our belief that, in spite of apparent similarities in the problem, the findings from the electron storage rings are not as relevant to us as those from proton rings. More specifically, we reject the assertion made at other places that the results obtained in electron storage rings prove the untenable nature of the pp and $p\bar{p}$ collidings with bunched beams. If we learned anything significant in the past year, it is to free us from the trap of fancy but not very realistic item such as the Arnol'd diffusion (which after all has been established only for a single unrealistic model) and to go back and reconsider the bread-and-butter items like resonance crossings, chromaticity and the RF noise. We should certainly pursue the theoretical work and the numerical simulation; they are definitely important in understanding the problem. At the same time, findings from the beam studies at CERN and at Fermilab should always be the most significant source of our knowledge not only at the present time but in the immediate future as well.

Experiments in the CERN ISR[10] with a bunched beam colliding with a coasting beam have established that the beam is stable at least up to ξ (linear tune shift) = 0.003/intersection. With eight intersections, the actual tune shift measured was 0.018. According to F. Mills, there is an experiment by B. Zotter which clearly demonstrated the importance of the tune modulation. There is a definite beam-beam effect with $\xi = 0.003$ if two beams are separated by ± 2 mm ($= \pm\sigma$) at four intersections. Presumably, the symmetry is lost and resonances of odd orders are created in this setup. The beam-beam effect however disappears when the RF is turned off and the momentum oscillation is eliminated. Since the chromaticity was not zero in this experiment, a tune ripple must have existed when the RF was on. A similar value of ξ has been found in the SPS in which special nonlinear lens (which was originally used by Keil and Leroy in the ISR beam studies) has been used to obtain the necessary tune shift. One important finding in this experiment was that the lifetime decreases from 4.5 hours to 1.5 hours when the 5th-order resonance is affecting the beam. With the 12th-order resonance, the lifetime was 3.5 hours. It is probably prudent to assume that, for the bunched beam, resonances of up to the order 15 or so are potentially harmful to the beam. The importance of controlling the chromaticity has been conclusively demonstrated in the recent main ring storage study.[6] By reducing the chromaticity $(\Delta\nu)/(\Delta p/p)$ from -17 (horizontal) and -11 (vertical) to essentially zero in both directions, it was possible to increase the half-life of 100 GeV bunched beam from $\sim$40 min. to $\sim$90 min. With the finite values of chromaticity, resonances crossed by the tune oscillation were those of the order

7 and 9. The other significant finding from this experiment was the strong effect of the 5th-order resonances on the beam loss rate. It is interesting to see that, in the SPS, there was a pronounced beam size increase at the beginning of storage. This has not been observed in the recent main ring studies. Since field quality of SPS magnets is definitely superior to that of main ring magnets, the beam size increase (which is equivalent to the reduction in the luminosity lifetime) observed in the SPS must be coming from something other than the magnet field. This is an example which shows that the field quality of magnets alone cannot decide the beam behavior in a storage ring.

Our plan is then to select the optimum point in the tune diagram between 19.37 and 19.45 (or, equivalently, from 19.63 to 19.55).[14] The distance to the nearest sum resonance is 0.012 if resonances of order 12 and lower are considered. The distance is down to 0.008 if the highest order is increased from 12 to 16. At 1 TeV/c, the beam emittance should be 0.025π mm-mr or less so that the tune spread in the beam is practically all from the beam-beam interaction and very little from the nonlinear field of magnets. With $\xi = 0.003$, the tune spread is also of this order. If we control the combined effects of tune spread and tune ripple arising from the power supply ripple and from the non-zero chromaticity to within 0.005, all sum resonances of order 16 and less are avoided. At present, there is no reason to suspect that this is an impossible requirement for the doubler.

<u>Note added on July 3, 1980</u>

I have just received a very interesting (and a very important) report from CERN on their beam storage studies in the SPS using the Keil-Leroy nonlinear lens (SPS Improvement Report No. 180). Results of these experiments strengthen my conviction that the principle stated in the last paragraph of this report is indeed the right one.

References

1. "A Report on the Design of the Fermi National Accelerator Laboratory Superconducting Accelerator", May 1979, Chapter 7.
2. "The Quadrupole Component in Dipoles and the Injection Mismatch", UPC No. 123 (3/6/80).
3. "Correction of Skew Quadrupole Field in the Doubler", UPC No. 125 (3/26/80).
4. "Field Quality of Doubler Dipoles and its Possible Implications", TM-910 (10/15/79) and TM-910A (11/6/79).
5. "Guidelines for the Field Quality of Doubler Quadrupoles", UPC No. 116 (11/19/79).
6. "The Lifetime of Bunched Beam Stored in the Main Ring at 100- and 150-GeV", FN-324 (4/14/80).
7. "The Effects of Power Supply Ripple on the Energy Doubler", UPC No. 102 (6/4/79); "Ripple Currents in Doubler During Storage Mode", a memo from R. Shafer to S. Ohnuma, 2/12/80.
8. "Longitudinal Instabilities Revisited", UPC No. 128 (4/8/80) and UPC No. 128A (4/22/80).
9. G. Guignard, "Review of the Investigation on the Beam-Beam Interactions at the ISR", CERN ISR-BOM/79-28, March 1979.
10. Three informal reports on the ISR bunched beam storage studies, run #1060, run #1073 and run #1080; letters from E. Keil to S. Ohnuma and one from G. Guignard to S. Ohnuma.
11. SPS Improvement Reports #107, #127, #154, #162, #163 and #167 on their intense single bunch storage studies.
12. Notes taken by F. Mills at CERN during the Workshop on Beam-Beam Interaction and Other Problems of the CERN $p\bar{p}$ Collider.
13. S. Kheifets, "Recent Experimental Results on the Beam-Beam Effects in Storage Rings and an Attempt of Their Interpretation", a talk given at Fermilab on February 21, 1980.
14. "Transverse Instabilities and the Correction Octupoles in the Doubler", UPC report in preparation.